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COSMONAUTICS: PRESENT AND FUTURE (BASED ON MATERIAL FROM THE FOREIGN PRESS)

by Leonid Efimovich Levant

"Kosmonavtika: Sostoyaniyei Perspektivy (po materialam zarubezhnoy pechati)" Znaniye, Moscow, 1974

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON, D.C. APRIL 1975

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This is a handbook on American cosmonautics based on foreign publications, particularly review articles contained in the yearbook, "Science and the Future," published by the well known *Encyclopedia Britannica*.

The handbook will appeal to a wide circle of readers.

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FROM THE EDITOR

The most remarkable of the many prominent scientific and technological achievements of the twentieth century are the launching of the first artificial Earth satellite and man's first entry into space, both accomplished in the Soviet Union. This first step — a great victory over the forces of nature, opening the road to space for all mankind — is a turning point in the history of our civilization on Earth. /3*

During the last 13 years, a short time even for our dynamic century, Soviet cosmonautics has made great strides forward. To its credit is the launching of hundreds of cosmic devices and a large number of manned spacecraft; the creation of the first experimental station in orbit and the first permanent scientific laboratory; and studies of the Moon and the planets of the Solar System by many interplanetary space probes.

The flights to the Moon by the American ships of the Apollo series are a great new achievement in man's conquest of space. Along with such events as the first launching of an artificial Earth satellite, Yu. A. Gagarin's flight in the Vostok /4
spacecraft, A. A. Leonov's walk in open space, and the studies of the planets Mars and Venus, the first walks on the surface of the Moon represent one of the most important events in the history of the development of cosmonautics.

On May 24, 1972, an agreement between the governments of the USSR and the USA was signed which commits the two parties to the

*Numbers in the margin indicate pagination of original foreign text.

mutual development of unified methods of approaches and docking of spacecraft and stations. As the first experimental stage, this agreement specifies that in 1975, there will be an approach, docking, and combined flight of a Soviet "Soyuz" spacecraft with an American Apollo craft. Also included in the flight program are crew transfers from one ship to the other.

The present collection was compiled from material in foreign publications, in particular, the review articles on astronautics and space research taken from the "Science and the Future" annual of the *Encyclopedia Brittanica*.

The collection consists of three basic headings: 1) launches of artificial Earth satellites; 2) flights of interplanetary space probes; and 3) flights of manned spacecraft.

In itself, of course, the present collection can hardly pretend to present a complete picture, if only because of its brevity. However, in view of the tremendous interest in the forthcoming joint flights, the events and facts elucidated in this collection may help the reader to better understand the present state of American astronautics and some of the prospects for man's further advances into space.

COSMONAUTICS: PRESENT AND FUTURE
(BASED ON MATERIAL FROM THE FOREIGN PRESS)

Levant, Leonid Efimovich

Artificial Earth Satellites /5

Artificial Earth satellites, depending on their purpose, can be divided into two basic groups. One large group consists of the satellites to be used for practical aims; these include satellites for communications and for studies of the earth's resources, as well as meteorological, geodesic, and navigation satellites. By coincidence, the first satellites in almost all these categories were launched in the USA almost simultaneously, in 1960. There is also another complete group of satellites designed for astronomical studies.

Meteorological Satellites and the Program of Earth Resource Studies

In 1974, an international program of atmospheric studies (GARP) will begin under the aegis of the International Meteorological Organization. Meteorological satellites will play an important part in this work.

Satellites for meteorological observations, which now serve practically all regions of the globe, have greatly improved the completeness and accuracy of weather forecasts. They represent a very important means of meteorological studies, since 70% of the Earth is covered by water and, in addition, there are no corresponding observation stations in the uninhabited parts of

the globe. Meteorological satellites have proved very useful in forecasting weather conditions that are dangerous to livestock; /6 they also provide weather reports for ocean shipping, reports and forecasts of ice cover on seas and lakes, and forewarnings of hurricanes and storms. Because of the satellites, there has been a significant improvement in the quality of short and long range weather forecasts, which has helped to minimize the material losses due to natural disasters. According to NASA estimates, the improvement in weather forecasting, resulting from the Nimbus satellites alone, leads to annual savings of more than two billion dollars.

In the USA, at present, two systems of meteorological satellites, developed on the basis of the earlier TIROS satellites, are in operation. These are the second generation ITOS (Tiros M) meteorological satellites, under the control of the National Administration of Oceanic and Atmospheric Research (NOAA), and the experimental satellites of the Nimbus series, which are fitted with more modern apparatus than the ITOS. By the end of 1973, four satellites of the ITOS (Tiros M) series and five of the Nimbus series had been launched successfully. All of these were placed in solarsynchronous polar orbits.* Twice a day (at 9 a.m. and 9 p.m. local time on the equator for the ITOS) the satellite passes over each point on the globe, which allows the meteorologists to compile a temperature grid of the entire Earth every 12 hours. More than 500 different stations in 94 countries can interrogate the satellite directly and obtain the necessary information. For this purpose, the information is

*The angular displacement of a satellite in solarsynchronous orbit is equal to the angular motion of the Earth around the Sun. The orbit rotates so as to follow the Sun and moves synchronously with it. In this way, the satellite can take multiple photographs of the same region of the Earth at the same angle of Solar elevation.

collected and stored on the satellites, to be sent on command to a ground station.

The development of the Nimbus series of experimental meteorological satellites was begun by NASA in 1960. In 1964, the first satellite of this series, the Nimbus 1, was launched. The launch of the last in the series, the Nimbus 6, is planned for 1974. As the Nimbus satellites have been improved, the range of the problems in their research program has widened, and their apparatus has been improved both quantitatively and qualitatively. Nimbus 3 carried the first apparatus capable of long distance atmospheric probing, which was later included in the ITOS satellite series. Depth probing makes it possible to obtain the /7 temperature distribution versus height, from the Earth's surface to the upper layers of the atmosphere. The information obtained annually in this way is equivalent to the launching of 10,000 balloons or rockets for the same purpose. The microwave apparatus included in the Nimbus 5 (which is twice as heavy as the ITOS) makes it possible to determine the temperature distribution in the atmosphere, the precipitation zones, and the boundary of the ice cover on the ocean, independently of the cloud cover of the planet, which hides 50% of the Earth's surface from satellites.

Nimbus 5 can collect and save up to 645 million bits of information. To accurately and rapidly (within 10 minutes) receive such a large quantity of information, the ground stations make use of the ATS technological relay satellites, which are placed in geosynchronous orbits.* The ATS technological satellites are also used as relays for the ITOS meteorological satellites. In addition, the ATS satellites, which are in geosynchronous orbits, can be used directly for meteorological

*A geosynchronous or stationary orbit permits the satellite to remain permanently over the same region of Earth.

purposes, since although their equipment is less modern, it provides more detailed information about the growth of storms or hurricanes in the open sea. In this lies the advantage of all stationary satellites, which remain "motionless" over any given region of the Earth's surface. For this reason, in 1974, it is planned to launch into geosynchronous orbit, two new meteorological satellites, SMS and GOES, which will have meteorological research devices of better quality than those on the ATS. These satellites will be the first elements in a system of four or five stationary satellites (from the USSR, USA, France, and, possibly, Japan), which is planned by the International Meteorological Organization in connection with the GARP program. This system should provide for the collection of weather information in the low and medium latitudes of Earth. These satellites will, on the one hand, take photographs of the cloud cover, measure the surface temperature of the sea, and determine the depth /8
distribution of temperature in the atmosphere. On the other hand, they can be used as communications satellites to transmit pictures of the cloud cover and facsimile weather maps from a central gound station to the regional centers.

The first satellite in the SMS series will be launched over the Pacific Ocean, and the second — over the Atlantic Ocean. They will transmit photographs of the cloud cover every 20 minutes; the rate of transmission of the meteorological information from the satellite to the ground receiving station will be 25 million bits per second.

The expanded capability of the scientific apparatus on the Nimbus satellites makes possible the use of the information thus obtained not only for meteorological purposes, but also for research in areas such as oceanology, hydrology, geology, cartography, agrotechnology, and Earth resource studies. For instance, observations by the Nimbus 4 were used in a study of

the type and amount of pollution in the waters of the Miami River and Lakes Ontario and Erie. Additional studies were made of volcanic activity in Hawaii and cave formations in Montana.

On the basis of the Nimbus series of meteorological satellites, the first American ERTS satellite for studying natural resources was developed. The range of possible uses for this satellite is very broad, and the information that it gathers can be applied in many branches of science. The following is a list of some of the advantages that scientists have gained from the use of satellites to explore the natural resources of Earth.

1. In agriculture, the information thus collected helps in the planning of land use, the detection and eradication of diseased grain cultures, and the planning of irrigation systems.

2. In geology, scientists use the data obtained by satellites to monitor the activity of glaciers and volcanos, to improve the forecasting of earthquakes, and to detect surface singularities that are related to deposits of oil and valuable minerals.

3 In hydrology, a system of these satellites promises to provide information that is useful in the detection of water pollution, in determining the water level in lakes and other reservoirs, in determining the level of snow cover and rain /9
waters, in forecasting the possibility of floods, and in locating other water resources.

4. In oceanography, the ability of data units on the satellites to detect and record changes in sea temperatures can provide information that is useful to studies of the behavior of schools of fish. This information also promises to be

valuable to commercial shipping, in providing more accurate maps of weather conditions on the ocean, locating ice fields, and giving warning of icebergs.

5. In geography, the data units on the satellites can compile maps that show the various changes in the Earth's surface resulting both from natural forces and from the intervention of man. This information promises to be extremely valuable for urban development and the planning of transport systems.

In order for the ERTS to fulfill such a broad range of purposes, the apparatus of the Nimbus satellite had to be increased considerably, leading to a weight increase of nearly 200 kg. In addition to the extra equipment, the satellite also had a hydrazine motor to be used for the occasional trajectory corrections of the satellite made necessary by the braking effects of the atmosphere.

The first satellite of this series, the ERTS 1, was placed in a circular and nearly polar solarsynchronous orbit (see the footnote on page 2) in June, 1972. Making 14 orbits per day, it appeared every 18 days over the same region of Earth, having "inspected" almost the entire surface. During each day, the ERTS 1 took 188 photographs of the surface with a resolution of 90 meters. The data from the satellite were received by a ground station, where the data were compiled and transmitted to the users, which included 33 countries and 2 international organizations. The functional lifetime of the ERTS 1 was estimated at one year.

During this period, more than 60,000 photographs of the Earth's surface were obtained. At the end of the period, the ERTS 1 continued its work, although the greater part of its equipment had ceased functioning. At the very beginning of its /10

operation, the system of television cameras on the ERTS 1 went out of order, followed by one after another of the video recording devices. However, the information that was obtained was very valuable and extensive. In particular, several previously unknown lakes were discovered in Iran. It was found that earlier maps of the Amazon River channel were in error by up to 30 km in some places. In addition, a new island with an area greater than 2 km^2 was detected. From the nature of the contours and color of the surface, nickel deposits were discovered in Western Canada, and copper deposits in Pakistan. Unknown volcanic craters were discovered in Nevada. Information from the ERTS 1 was successfully used in Ghana in the battle against locusts, etc. The data from the satellite are still being processed. About 300 scientists from nearly 50 countries are participating in this work. This further processing will undoubtedly lead to new discoveries. The launch of the ERTS 2 is set for 1976; in addition, four more launchings of satellites in this series are planned for the end of the 1970's.

Communications Satellites

August, 1974 marks the tenth anniversary of the founding of Intelstat, the international organization for satellite communications between continents. Despite the international makeup of this organization, it remains essentially American, since 95% of its financing was provided by American firms, and the other countries are involved only as consumers.

In August of last year, the fifth and last satellite of the Intelstat 4 series was successfully placed in a geosynchronous orbit (see the footnote on page 3). The Intelstat 4 system of five satellites provides a communications link between 73 ground stations (91 antennas) in 55 countries. In all, during the existence of Intelstat, 14 satellites of four "generations"

have been launched successfully. In this period, the lifetime of the satellites in orbit has increased by nearly a factor of 20, and the number of telephone channels that can simultaneously operate on each Intelstat satellite has increased greatly. The latter fact has reduced the cost of creating a single telephone channel in the communications satellite system, from 25,000 /11
dollars a year for the Intelstat 1 satellite to 700 dollars a year for the Intelstat 4 satellite system.

A fourth-generation satellite of the Intelstat 4 system can simultaneously handle 6,000 to 7,000 telephone channels or 12 channels of color television. The satellite weighs 1,100 kg and has a lifetime of 7 years. In shape it is a cylinder of length about five meters and diameter about two meters, and its power is supplied by solar batteries.

A new system of communications satellites, the Intelstat 4A, is now under development; it will consist of three Intelstat 4A satellites, two to be launched over the Atlantic and one over the Pacific Ocean, together with one Intelstat 4 satellite over the Indian Ocean. The first satellite in the Intelstat 4A series will be launched in the middle of 1975. Each of the satellites in this series will have a length of ~ 6 meters, diameter ~ 2.5 meters, and weight 1,460 kg. The functional lifetime will be seven years (the same as Intelstat 4). It will be able to handle simultaneously about 10,000 telephone channels or 20 to 24 television channels.

Intelstat 4A represents an intermediate type of communications satellite. After 1977 — 1978, it is planned to create a new generation of satellites, the Intelstat 5. Each of these will be able simultaneously to handle up to 30,000 telephone channels and will have a functional lifetime of ten years. The overall cost of the Intelstat 5 program is estimated at 266 — 305

million dollars. Many non-American firms will participate in the financing of the Intestat 4A and 5 systems. However, the prime responsibility for this program will rest with the USA, which provides the booster rockets for launching all the satellites of the Intelstat organization.

What are the future prospects for satellite communications? These satellites still have a strong competitor in the telephone cables laid along the ground or on the bottom of the ocean. However, the best of these cables in 1970 could handle simultaneously only 720 telephone channels, which is only about one-tenth of the carrying capacity of an Intelstat 4 satellite. Future increases in carrying capacity will reduce the cost of satellite communications. Refinements of the methods of information transmission will also aid in this respect. A method has been /12
developed for transmitting numerical data through the Intelstat satellite link at the rate of 56,000 bits per minute. By the use of this method, a single telephone channel can take the place of twelve channels in transmitting the same amount of information.

On the other hand, the Intelstat communications satellites still have very low power and a very narrow directional effect, and they require huge and expensive ground receiving stations with antennas of diameter 26 — 30 meters. These stations are commonly quite far from the individual consumers and must be manned by qualified specialists. For these reasons, the Intelstat satellite system is used primarily for telephone communication (in 1971 television transmissions amounted to only 17% of the operation of Intelstat, which corresponds to 1/10 of the load on the satellite television channels).

NASA has already been working for several years to develop a satellite capable of direct television broadcasting to home

receivers. Such a satellite requires a high transmitting power and a large antenna. For this year, NASA has scheduled the launch of the experimental technological satellite ATS 6(F), which among other tasks, will be used to relay educational television programs to simple and inexpensive ground receivers. This satellite is designed to take part in an unusually broad range of studies. It will be used for navigation and meteorological purposes and, also, to try out a new stabilization system and a new type of ion electric motor.

The ATS 6 will be the first satellite to carry data units that operate in the 20 — 30 GHz frequency range. A system of satellite communications using these frequencies has considerable advantages over the existing systems, which operate at lower frequencies (due to the lower costs involved in using the latter). In the 20 — 30 GHz range, there are ten times as many communications channels as in the 4 — 6 GHz frequency range presently in use. Among the first uses of the 20 — 30 GHz range, it is proposed to study the propagation of radio waves with this frequency in the Earth's atmosphere. /13

The ATS 6 will also be used for the purpose of a national satellite communications system for the USA. To date only the USSR and, recently, Canada have had national satellite communications systems. Communications by satellite for the entire territory of a country are also under development in other countries: England, India, Spain, Italy, France, West Germany, Japan, and the USA. Despite its active participation in Intelstat and in the development and launching of the Canadian communications satellite Anik, the USA does not yet have its own national satellite system for television broadcasts, operating only within the limits of the USA. ATS 6 will be the first to be used for this purpose, but only experimentally.

However, as noted above, one of the basic purposes of the new satellite will be a program, developed in concert with the government of India, of direct television broadcasts intended to assist in the education of the illiterate population of the latter. The ATS 6 will relay signals from the Indian transmitting center back from space to 5,000 Indian villages, in which it is planned to erect small and inexpensive receiving antennas, and at least one cheap large screen television set. The initial broadcasts will be devoted to agricultural problems and methods of birth control. It is proposed, later, to expand the framework of this experiment and establish direct communications between all the villages of India (of which there are about 560 thousand). One reason for this program is that India has no ground links for network television transmission and lacks the means to create them. The total cost of this program of educational television broadcasts through the ATS 6 is estimated at 300 million dollars.

The idea of mass education by means of television broadcasts using the ATS 6 has aroused widespread interest. The possibility of creating space television broadcasting systems of this sort is being studied in other countries of the Americas, in the Arabian subcontinent, and in Australia.

The operating lifetime of the ATS 6 is estimated at five years. In its basic construction, the satellite is a lattice framework with a container holding the basic apparatus attached to one end and, on the other end — a 9 meter parabolic antenna (the largest ever used in space) and the system of solar batteries. The weight of the ATS 6 is 1,200 kg. It will /13
initially be placed in a stationary orbit (see the footnote on page 3) over the Western Hemisphere, and, at the end of a year, it will be moved to the Eastern Hemisphere, directly over India.

In addition to the satellites with practical applications cited above, there also exist many other types used for navigation, geodesics, ionospheric, and atmospheric research, etc. One very special group comprises the astronomical satellites, which have already been used in many discoveries in the areas of astronomy and astrophysics.

Astronomical Satellites

The development of space technology has brought about a revolution in astronomical research. Astronomical observations on Earth have always been confined to a few narrow ranges of the spectrum of electromagnetic radiation from stellar objects — the optical and radio bands. Radiation in the infrared, ultraviolet, x-ray, and gamma ray bands of the spectrum is absorbed by the Earth's atmosphere. Long radio waves from space are reflected by the ionosphere and, thus, also are inaccessible to observers. The use of rockets or balloons to carry the apparatus beyond the atmosphere has led to many discoveries in astronomy. However, the short observational period available to the apparatus during a rocket flight (no more than two minutes) sharply limited progress in the new science of super-atmospheric astronomy. Only with the launching of astronomical satellites, whose operating times are measured in years, has it become possible to accumulate and systematize a large volume of observational material and to raise superatmospheric astronomy to its proper place among the branches of science.

A whole series of astronomical satellites has been developed in the USA. These include, primarily, the Orbital Astronomical Observatory (OAO), the specialized satellites for observations in the x-ray and gamma ray regions of the spectrum (SAS), the Orbital Solar Observatory (OSO), and several others.

The development of the OAO satellites, designed for observations in the ultraviolet and x-ray bands, began as early as 1959. The first satellite of this series, the OAO 1, was launched in 1967, the OAO 2 — at the end of 1968, and the last, the OAO 3, in August, 1972. At the beginning of last year, the operation of the OAO 2, which was designed for observations in the ultraviolet range, was shut off. This 1,980 kg satellite, which was expected to operate for one year, remained in operation for more than four years. During this time, it carried out a total of 22,560 observations of 1,930 stellar objects. Observations of the galaxies showed that the intensity of their emissions in the ultraviolet was somewhat higher than had been supposed earlier. In the Andromeda galaxy, an intense blue region was discovered, concentrated within 2' of the galactic core. The nature of this ultraviolet splotch is evidently related to activity in the core of the Andromeda galaxy of which nothing was known earlier. /15

The OAO 2 was also used to carry out studies of the ultraviolet radiation from many of the planets of the Solar System: Venus, Mars, Jupiter, Saturn, and Uranus (the latter for the first time). An analysis of the features of the ultraviolet radiation from Mars showed that the ozone content in its atmosphere is 1,000 times smaller than that of Earth, so that the surface of Mars is "unprotected" from the destructive effects of cosmic ultraviolet radiation. At the start of 1970, the apparatus of the OAO 2 was directed toward the newly discovered Comet Tago-Sato-Kosaka, leading to the discovery of a huge hydrogen cloud around the Comet, comparable in size to the Sun. The equipment on the OAO 2 provided the first information about ultraviolet radiation from supernovas, established the presence of magnesium in the atmospheres of cold giants and supergiants, and helped to broaden our knowledge of the Earth's upper atmosphere.

The two-ton OAO 3 satellite was launched into a near-polar orbit on the threshold of the year 1973, when all the world was preparing to celebrate the 500th anniversary of the birth of the famous Polish scientist, Nicolaus Copernicus. In honor of this event, the satellite was named after the scientist.

The OAO 3 (Copernicus) is in the form of an octahedron of /16
3 meters length and 2 meters diameter. Its principal instrument is an 80 centimeter ultraviolet telescope with an orientation accuracy of 0.1". In addition, in connection with an experiment that was planned and carried out by English scientists, the satellite carried a detector of cosmic x-radiation. The cost of the launch and the satellite itself amounted to 176 million dollars.

At the present time, the equipment of the satellite is still operating successfully, although it has completed all the tasks that were originally set for it. Important facts about the nature of interstellar dust clouds were discovered. They were found to contain a large quantity of molecular and atomic hydrogen, together with some heavy elements. An analysis of the results also indicates the presence of solid particles of much smaller diameter than had earlier been thought to exist in such clouds. The most striking result was the detection of large amounts of deuterium in interstellar space, which does not agree with the conclusions of many theories of star formation. The presence of deuterium in interstellar space was quickly confirmed by radio-astronomical observations on the ground. The use of the x-ray detector led to considerable advances in our understanding of the nature of many cosmic ray sources, including x-ray pulsars in particular.

The experimental program of the specialized SAS satellites included studies of the cosmic radiation in the x-ray and gamma ray bands of the spectrum. The first satellite of this series,

the SAS A (also named Uhuru), was launched in December, 1970, into a nearly circular orbit at an inclination of 3° to the equator. This inclination was necessary in order to eliminate the undesirable effects of anomalous magnetic regions on the satellite equipment. For this reason, all the SAS satellites have been launched from the San Marco floating platform near Italy, since it is energetically more favorable to launch a satellite into such an orbit (with a small inclination to the equator) from this point than it would be from any point within the boundaries of the USA, which lies at higher latitudes.

SAS A was designed to study cosmic x-radiation, including that from the cosmic x-ray sources whose existence was unknown before 1962. In order to orient the x-ray detector with an accuracy of ≈ 1', a system of two stellar and two solar orientation units was used. The satellite weight was 157.5 kg, of which the two x-ray detectors made up 70 kg. The satellite is still in operation at the present time (although with reduced efficiency). /17

The last SAS A catalog, published at the end of 1973, contains information about 163 x-ray sources. To fully estimate the value of the research performed with the SAS A, it must be noted that only 35 cosmic x-ray sources were known before it was launched. Among the sources that it "discovered" are many that were known earlier from their radiation in the optical and radio bands of the spectrum. These include the remnants of supernovas (particularly, the radio pulsar in the Crab Nebula), some stars, galaxies, quasars, and even whole clusters of galaxies. Some of the x-ray sources show behavior resembling novas.

One important discovery of the SAS A satellite was the existence of x-ray sources occurring in double star systems, in which one of the components is a normal star, and the other

is a compact object that radiates in the x-ray band. Six such systems were already known at the end of 1973. The most unusual point is that at least two of these sources are x-ray pulsars, i.e., the variations in their x-ray intensity exhibit strong periodicity. If this periodicity is due to the rotation of the source, it must be of very small dimensions, and most probably is a rotating neutron star. The Cygnus X-1 double star is particularly interesting. Although it exhibits no strong periodicity, estimates of its mass and size indicate that it too is a neutron star, or else, as some astrophysicists have suggested, a "black hole" (an object whose radius is smaller than the critical gravitational value, as predicted by the general theory of of relativity). Another object with unique properties is the double x-ray source LMC X-1, which lies in the Lesser Magellanic Cloud. It radiates energy at a rate of 10^{39} erg/sec, which is an order of magnitude higher than the critical Eddington limit of radiation from a star with one solar mass. /18

From the data of the SAS A, more than 40 of the x-ray sources appear to be extragalactic (only six of this type were known before the launching of the satellite). They have been identified both as normal galaxies and as unusual galaxies of the Seifert or radiogalaxy type. The x-radiation from the closest known quasar 3C 273 was also verified. The most surprising result of this research, however, was the discovery of extended regions of high x-ray emission in some galactic clusters. Many hypotheses have been offered to interpret this result, but no complete explanation has yet been found.

In November, 1972, the second satellite in the series, the SAS B, was launched from the San Marco platform; it was designed to study cosmic gamma radiation. The SAS B is 0.55 m in diameter and 1.29 m long, and weighs 186 kg.

If we may say that its predecessor, the SAS A, "discovered" the new science of x-ray astronomy, then the role of the SAS B was much more modest, and this is not because its equipment functioned for only half a year before going out of order. During this time, it had already succeeded in "examining" all of the most interesting parts of the sky from which information about cosmic gamma radiation was expected. The reason for the "failure" lay in the SAS B itself. Its equipment was still far from perfect and could not have led to any great discoveries in gamma-ray astronomy. The scientists who developed the satellite regarded it as merely experimental, hoping to use the information obtained from the construction of the SAS B to build better apparatus for the HEAO satellite, the launching of which is planned for the end of the 1970's or the beginning of the 1980's.

Nevertheless, a great deal of interesting information was obtained for the SAS B observations of the distribution and spectral characteristics of diffuse cosmic gamma radiation. The SAS B data on the gamma radiation of our own galaxy, particularly its central regions, are also of great interest. The extended source of gamma radiation lying in the plane of the galaxy and close to its center was confirmed and studied in greater detail. /19
More reliable observations were made of the gamma radiation from the Crab Nebula, which so far is the only known discrete source of gamma radiation in this band of the electromagnetic spectrum. The results are also of great value to cosmology. Estimates of the characteristics of the observed background (extragalactic) diffuse gamma radiation have a strong influence on the scientists' choice of one or another model of the universe.

At the beginning of this year, from the same San Marco platform, the third satellite of the series was launched, the SAS C, designed to carry out further studies of cosmic x-radiation.

Its work has just begun. In England and the USA, joint development is proceeding on the fourth satellite, the SAS D, which will be designed for astronomical observations in the ultraviolet part of the spectrum. It is expected to be launched before 1976, and its operating lifetime is estimated at three to five years.

Besides the astronomical satellites listed above, the USA has launched many others, particularly the OSO series of satellies, which were designed for solar observations. A great deal of information has been obtained from these satellites about the star that lies closest to us, about the processes that occur in its interior, and about the nature of solar activity. With the help of a gamma ray detector carried by one of the latest satellites in the series, the OSO 7, a line spectrum of gamma radiation from the sun was detected, which serves as direct proof of the nuclear reactions occurring in its interior. This is the first confirmation of the theory of nuclear heating as the primary source of stellar energy. The observed gamma radiation coincided exactly with a strong peak of solar activity in August, 1972. This implies the existence, during the peak, of a tremendous number of particles with the very high energies needed for the occurrence of nuclear reactions.

The latest discovery in superatmospheric astronomy was made by the Vela satellite, which was never intended for astronomical studies. The high quality gamma ray detector installed on this satellite recorded puzzling, extremely short bursts of gamma radiation whose origin appeared to be completely unrelated to the Solar System. These bursts were later observed /20
by other satellites: the OAO 3, the OSO 7, and yet another astronomical satellite, the IMP 6. One of the bursts was also recorded in the x-ray band by the SAS A satellite. The nature of these bursts is still unclear, although several astrophysical hypotheses have been offered to explain the phenomenon.

At the end of the 1970's, it is planned to put in orbit the "Large Space Telescope" (LST). This will also serve to widen the horizons of ground astronomical observations, since the atmosphere of Earth has a very strong effect even in the optical band.

Interplanetary Space Probes

Mars Studies

The development of space technology has come very close to solving the "eternal" question of the presence of life on Mars, the only other planet of the Solar System on which, as many scientists think, conditions suitable for life may exist. Mars studies with the help of interplanetary space probes have made up a considerable part of the USA space program.

As early as June, 1965, the American probe Mariner 4, on its approach to Mars, took the first photographs of the planet from such a close distance. In these photographs (21 in all), the surface of Mars was found, to the surprise of many, to be covered with numerous craters, much like the surface of the Moon. As we now know, Luna is a planet "dead" in the geological sense, on which the conditions for life do not exist. It was, therefore, with great interest, but some "watchfulness," that the results were awaited from two other Mars probes, Mariner 6 and Mariner 7. On July 31, 1969, Mariner 6 flew by Mars at a distance of 3,400 km from the equator. Five days later, Mariner 7 flew by at the same distance over the south polar cap of the planet. While they flew past the planet, they took 143 photographs of Mars, 53 of which were taken at the period of /21
closest approach. In these photographs, covering 20% of the surface of Mars, it was possible to distinguish details 270 meters wide (the resolution of the photographs taken by the

Mariner 4 probe was only sufficient for details one kilometer in width). Analyses of these photographs, together with measurements of the atmospheric characteristics of the planet, disheartened many scientists who had believed in the possibility of life on Mars. The analyses showed that there is practically no water in the liquid state on any of the warm regions of the surface of Mars, and none at all in the form of ice on the polar caps. The surface of Mars was seen to be entirely mottled with little craters and with no signs of volcanic activity. These facts, together with the very low surface temperature and the high permeability of the atmosphere, which freely passes ultraviolet cosmic radiation, are fatal for living creatures and have almost certainly disproved all the various hypotheses about the possibility of finding life on Mars.

Nevertheless, despite the pessimistic attitude of many specialists after the Mariner 6 and 7 photographs, NASA continued to develop a project for a soft landing on Mars in 1976, the Viking space probe, whose chief task will be to detect life on the surface of the planet. Mars flights by the Mariner 8 and Mariner 9 probes were also made ready. It is due to the successful flight of the latter and its results, together with the parallel researches carried out by the Soviet probes "Mars 2" and "Mars 3," that the view of Mars as a planet as "dead" as the Moon was completely overturned.

On November 13, 1971, five months after its launching, Mariner 9 entered into an orbit around Mars. Weighing 1,000 kg, it was fitted with two television cameras for taking pictures of the surface, plus apparatus for making studies in the infrared and ultraviolet bands of the spectrum. A number of circumstances, however, combined to force a change in the /22 research program originally scheduled for this probe. This was due to the unsuccessful launch of the other probe, the Mariner 8,

as a result of which the Mariner 9 program was supplemented with the tasks that had been assigned to the Mariner 8. Since this affected primarily the job of obtaining photographs of the entire surface of Mars, it was decided to change the originally planned orbit of Mariner 9. By moving the probe to a higher orbit and widening the scanning field of its television cameras, the NASA specialists hoped to have Mariner 9 carry out the program of both probes before its energy resources ran out. However, this plan was nearly ruined by a dust storm on Mars that completely hid the surface from the television cameras. A new orbit correction was made, which led to a lower resolution for the Mariner 9 cameras than had been calculated earlier. When it came time for the probe to pass over the shadowed side of Mars (during which time the television equipment could not be operated), the Mariner 9 had not yet succeeded in photographing the entire surface of the planet. With great impatience the NASA specialists awaited the reappearance of the probe from the dark side of Mars, which did not occur until two months later. However, when it returned from the dark side, Mariner 9 was able, not only to complete the photographing of the entire surface of Mars but, also, to take some additional pictures of some separate regions of the surface that were of the greatest scientific interest and, in particular, were considered candidates for the landing spot of the Viking probe in 1976. An experiment had even been planned to verify the theory of relativity. However, on October 27, 1972, because of the complete exhaustion of the fuel in its steering system, the probe began to tumble, and on its 968th orbit around Mars, the Mariner 9 cameras were shut down. According to NASA estimates, the probe will remain in orbit around Mars for another 50 to 100 years.

During its 517 days of operation in orbit, the Mariner 9 probe took 7,329 photographs, covering the entire surface of Mars. In addition, the onboard apparatus transmitted to the

NASA specialists about one million spectral readings of the planet in the infrared and ultraviolet bands. Analyses of these extensive observations together with the results of Mars studies /23 by the "Mars 2" and "Mars 3" probes have sharply altered our ideas about the planet in the aftermath of the photographs taken by Mariner 6 and Mariner 7. The Mariner 9 data indicate the presence of volcanic activity on Mars in the past; water vapor was found over the polar caps; long canyons were observed. These results indicate that the geological structure of Mars differs from those of the Earth and the Moon. It appears that Mars occupies a transition point between the relatively primitive and predominantly meteor-cratered Moon and the organically mobile, volcanically active, and predominantly water covered Earth.

As seen in the Mariner 9 photographs, several formations on the surface of Mars appear similar to terrestrial geological formations that have resulted from the action of flowing water. To explain these features is a serious problem, because the low pressure and temperature on Mars exclude any possibility of liquid water on its surface at the present time.

One interesting discovery was the detection of dune fields, consisting of loose material, on the bottoms of the craters. The similar dimensions and directions of the separate dunes indicate that they were formed by strong winds blowing in a constant southwest direction. The dunes at the edges are shallower than those in the middle, just as in terrestrial conditions. From the photographs taken of the polar caps, it is concluded that they consist primarily of frozen water and a very thin layer of carbon dioxide, which condenses in the winter.

Mariner 9 also obtained the first photographs of the moons of Mars, Phobos, and Deimos. The photographs showed the size

of the moons, which were found to be ancient, heavily cratered bodies of irregular shape. The largest crater on Phobos (5.3 km across) was probably formed by a collision with a body of almost the same size. The number of craters per unit surface on the moons is about two orders of magnitude higher than on Mars, which indicates the presence of erosion processes in the past on Mars.

In the opinion of the scientists, all these discoveries have /24 considerably improved the chances of detecting some traces of biochemical activity on Mars when the Viking biological "laboratory" lands in 1976.

Two Viking probes, weighing 3,600 kg each, will be launched ten days apart during the period between the middle of August and the middle of September, 1975. The flight from Earth to Mars will take 305 — 360 days. As it approaches Mars, the Viking probe will be put into orbit around the planet.

The Viking probe will consist of a landing module and an orbital module, as well as a system to provide a soft landing on the surface of Mars. The landing module and the landing system will be carried in a sterile hermetic container in the form of a sphere four meters in diameter, consisting of a lid and a bottom portion. The lid will be detached during the interplanetary trajectory, and the bottom portion — immediately before the descent of the landing module. The module will be launched at an altitude of 360 km with a velocity of 5 km/sec. In the first stage of the descent, the landing module will undergo aerodynamic braking by the atmosphere, which is assumed to begin at an altitude of 240 km. At about 6 km altitude, a parachute 16 m in diameter will open, later to be jettisoned at 1.6 km altitude. Three braking jets will then be turned on, which will operate for 5 — 10 minutes and provide a calculated

landing velocity of 2.4 m/sec. The landing system also includes a radio location device to permit corrections in the time of operation of the jets. Each of the jets has 18 nozzles in order to minimize the effects of the jet streams on the soil. The total landing time will be from 2 to 6 hours, after which the landing module, weighing about 550 kg, with the biological laboratory on board, will land "softly" on its three supports on the surface of Mars. For the next three months, its equipment will study the nearby soil and the surrounding area. Its principal task will be to look for living Martian micro-organisms.

Although the principal experiments are due to be performed on the surface of Mars, it is also planned to carry out various studies with scientific apparatus (weighing 65 kg) on the orbital module. This apparatus is scheduled to function for 50 days before the landing module is launched and for another 90 days afterward. In essence, it will be a copy of the similar apparatus on Mariner 9 and will carry out similar tasks: photographing the surface with a system of two television cameras, studying the distribution of water vapor in the atmosphere, and measuring the surface temperatures on Mars. The atmospheric characteristics will also be measured by devices on the landing module during its landing trajectory. In the first stage of the descent, these devices will analyze the composition of the upper atmosphere, in the lower layers of the atmosphere, they will determine the density, temperature, and pressure, and finally, during the parachute descent, they will measure the wind velocity. /25

The main experiment on the surface of Mars will be performed by the biological laboratory. For this purpose, the laboratory includes four devices, three of which are designed to measure the extraction of $C^{14}O_2$. The point of this is that if the soil samples, taken from the surface of the planet by a special mechanism, contain living organisms, then all the laboratory

apparatus will record the results of the action of the surrounding medium on the micro-organisms. In particular, when a soil sample is placed in a special container, they will be able to record the carbon exchange between the organisms and the medium, since then carbon-containing gases should be evolved, including the radioactive isotope C^{14}. It is proposed to use the fourth device to study the growth of the micro-organisms in the experimental sample. For this purpose a small quantity of water will be added to the soil sample as a nutrient medium. The device developed for this experiment can detect particles in the amount of 10^3 to 10^6 parts per million. If the analysis of the soil samples gives a positive result, in the sense of detecting signs of living organisms, then a further investigation of the "suspicious" samples is planned: they will be placed for three hours in a sterile chamber heated to 169° C and, then, subjected to another biological analysis.

In addition to the biological analysis of the Martian soil, other devices on the landing module will carry out another set of experiments. Among these will be the taking of pictures by two television cameras, molecular analyses, meteorological observations, studies of the magnetic and physical properties of the Martian soil, and an experiment in radio communication. The television system on the landing module will consist of two identical scanning cameras, which will scan the field of view with high resolution and in color. The cameras will be set one meter apart to obtain stereoscopic pictures. The meteorological experiments will include measurements of the wind velocity and direction, and of the pressure, temperature, and water vapor content of the atmosphere. To study the magnetic properties of the materials covering the surface of Mars, a system of magnets will be used, similar to that used successfully on the surface of the Moon by the Surveyor probe. A small seismometer will record surface vibrations. /26

The landing module will be fitted with two antennas, one highly directional for direct shortwave communications with Earth and one ultrawave antenna for communicating with the orbital module. Ultrawave communication to the orbital module and the use of the more powerful antenna on this module to transmit information to Earth will provide a much higher volume of transmission than would be possible directly from the surface of Mars. For example, by using the orbital module as a relay, the equipment on the landing module can transmit up to 20 photographs a day, but by direct communication to Earth, it can only send one photograph a day.

From detailed analyses of the photographs and other information obtained with the Mariner 9 probe, NASA has already decided on the landing points of the Viking. For the first Viking landing module, they have chosen a point in the Chrysa region (19.5° N. Latitude, 34° W. Longitude) at the northeast end of a 4,800 km canyon. The Chrysa region is an area of about 80 km by 580 km, lying at the mouth of the largest system of Martian "canals," which resemble the dry beds of terrestrial rivers. For the second landing point, the Cydonia region (44.3° N, 10° W) in the Acidalium "Sea" at the southern edge of the north polar cap has been chosen. Soviet and American probes have established that the temperature in this region rises to 0° C in the summer. Furthermore, water vapor has been detected /27
over this region. Both regions lie outside the zone of strong winds and are about 5 km below the average surface level. The distance between the two landing points is about 1,600 km, which will increase the effectiveness of the seismic measurements taken by the apparatus on the landing modules. The alternate landing points are also spaced apart; these are, respectively, Tritonis Lacus (20.5° N, 252° W.) and Alba (44.2° N, 110° W.).

The Viking launch will represent the first use of the new Titan-Centaur booster rocket, which is ~ 49 m long and weighs 640 metric tons. This rocket is still being developed. At the start of this year, its first flight tests ended unsuccessfully.

For several years now, a valuable tradition has existed under which Soviet and American scientists exchange extensive information about the results of space research, especially with respect to the planet Mars. For instance, at the time of the Soviet "Mars 2 and "Mars 3" flights and the American Mariner 9 flight, a communication line was kept constantly open between the Soviet Academy of Sciences in Moscow and the Jet Propulsion Laboratory in Pasadena. During the development of the Viking project, American scientists have followed with great interest the results of the successful first soft landings on Mars by the Soviet "Mars 3" and "Mars 5" probes. This has given rise to confidence that the soft landings of the Viking biological laboratories will be successful.

Studies of Jupiter and Saturn

Probe flights to the outer planets, i.e., the planets lying outside the orbit of Mars, which include Jupiter and Saturn, have always involved the problem of a safe passage through the asteroid belt. The asteroid belt, which encircles the Solar System between the orbits of Mars and Jupiter, consists of large scale objects measuring up to 767 km across (for the largest planetoid Ceres) and a great quantity of much smaller chunks and particles, which could endanger the "navigation" of a probe through this volume of space. In addition, in order for the probe to reach the vicinity of Jupiter, which is 3.5 times as far from the Sun as Mars, the probe launch velocity must be high /28 enough to overcome the gravitational attraction of the Sun. With such a velocity, the probe could escape from the Solar System and become the first pioneer on the path to the nearest star.

The first object created by the hand of man to overcome the solar attraction and escape the Solar System, will evidently be the American probe, Pioneer 10, which was launched toward Jupiter. Although the probability of its reaching the planetary system of another star is negligibly small, it is not impossible that some highly developed extraterrestrial civilization may someday distinguish this artificial object from among other bodies of natural origin. With this possibility in mind, the creators of the Pioneer 10 placed on it a gold anodized aluminum plate, measuring 15 by 23 cm, inscribed with a symbolic picture that reports the existence of a civilization on Earth. The left upper corner of the plate shows schematically the transition between levels in the superfine structure of the ground state of a hydrogen atom, since hydrogen is the most widespread element in the Universe. On the right side, are shown pictures of a man, a woman, and the outline of the Pioneer 10, all on the same scale. Below these pictures, the average height of a human being is written in binary code, using as the unit of length 21 cm, which is the wave length of the radiation from the transition between the superfine levels of hydrogen. Below and to the left, the Solar System and the flight trajectory of the Pioneer 10 are shown schematically, and the distances of the planets from the Sun are given in binary code, using the radius of Mercury's orbit as the unit length. Finally, on the left center of the plate is a diagram representing the positions and periods of 14 pulsars. The configuration of the positions, together with the periods of the pulsars, define the location of the Solar System and the launch date of the probe.

The Pioneer 10, weighing 258 kg, was launched on March 2, 1972. In the initial portion of its flight, its velocity reached 51,000 km per hour. On board the Pioneer 10 are 11 devices for studying the interplanetary medium, the asteroid belt, and the properties of Jupiter's atmosphere. Despite the enormous speed /29

of the probe, the highest ever attained by a spacecraft, it had a long flight to make, requiring 21 months of travel. At the end of 130 days it had to enter the asteroid belt, which was supposed to be extremely dangerous to the probe. During the flight of the Pioneer 10 to Jupiter, its trajectory was corrected several times by the use of auxiliary jets; the last correction was made in order for the probe to pass by Jupiter's moon Io and determine if the latter had an atmosphere.

On July 15, 1972, Pioneer 10 entered the asteroid belt, which is 80 million kilometers wide. The probe took 200 days to cover this distance. Its trajectory in the asteroid belt was chosen so as to keep the largest possible distance between the probe and the known asteroids. The closest approach of the Pioneer 10 was to the asteroids Palomar-Leyden and Nix. It was with great misgivings that the scientists awaited the probe's encounter with micrometeorites in the belt, but they had high hopes that the probe would detect some new large asteroids. Neither expectation came true. The information sent by Pioneer 10 from the asteroid belt was quite unexpected to astronomers.

The density of small particles (0.01 to 0.1 mm in diameter) in the belt, recorded by the particle detectors was considerably lower than had been believed. The frequency with which particles were recorded in the belt was found to be equal to the frequency measured on the trajectory before the probe entered the belt (it had been expected to rise by an order of magnitude). As a result, the meteor particle detector was left with a large reserve of cells unpunctured by micrometeorites. This made it possible to obtain information about the meteor situation at greater distances from the Sun, after the Jupiter flyby, than had been planned earlier.

In contrast to the fine particles, and also unexpectedly, a relatively high density of large particles (0.1 to 1 mm in diameter) was detected. Two bands of maximum density of these particles were recorded in the asteroid belt, at 400 and 480 million kilometers from the Sun, respectively. The velocites of large particles with respect to the probe were found to be very high, up to 16 km/sec for particles with diameters between 2 and 4 mm. Thus, the probability of damage to the probe by such /30 particles is somewhat higher than was believed earlier; nevertheless, in the opinion of the NASA specialists, it does not represent a danger to "navigation" in the asteroid belt.

In February, 1973, the Pioneer 10 probe successfully exited from the asteroid belt and began its approach to Jupiter with no difficulty whatever. On the night of December 3 and 4, 1973, it reached its minimum distance from the planet (130,000 km). During the flyby, the probe took 340 photographs of the planet and its four moons, Io, Callisto, Europa, and Ganymede. In the photographs, Jupiter appears covered by concentric silver-gray, orange, red-brown, yellow, and blue bands. The famous Red Spot can be seen on a silver-gray background. The probe also discovered a somewhat smaller White Spot (16,000 km across), which recalls a cluster of cumulus clouds on Earth.

According to the data from Pioneer 10, the planet has hydrogen and helium coronas. The upper layer of clouds consists of feathery clouds of ammonia, and the temperature of the cloud tops is 133° C. It appears that the intensity of infrared radiation from the sunlit side of the planet is the same as on the dark side. The magnetic field of Jupiter is very unusual. As the probe approached the planet, the field dropped off and increased again several times. A number of hypotheses have been advanced to explain this phenomenon.

Jupiter's radiation belt is also unlike that of Earth. The zone of highest radiation intensity lies in the plane of the planet's magnetic equator and was recorded at 177,000 km from it. As the Pioneer 10 passed through this zone, it experienced only minor damage.

Measurements of the trajectory showed that the planet is more massive than had been believed. The mass of Io was also found to be higher, and, in addition, Io was found to have a dense atmosphere. This information, however, is extremely provisional. The processing of the huge volume of data from the probe has only begun. Pioneer 10 will continue to recede from the Sun. /31
According to calculations, in 1987, it will intersect the orbit of Pluto and leave the limits of the Solar System in the direction of the constellation Taurus. American scientists hope to keep in contact with the probe until 1979. By that time, Pioneer 10 will cross the orbit of Uranus.

On April 6, 1973, 13 months after the launch of the Pioneer 10, the Pioneer 11 probe was placed in a trajectory to Jupiter. The Pioneer 11, almost completely identical to its predecessor, is intended to continue the study of Jupiter's atmosphere and the surrounding space. Only one device was added to the equipment on board the probe: an instrument to measure the intense magnetic fields that it is expected to find near Jupiter. On August 18, the probe entered the asteroid belt, from which it exited safely on March 12, 1974. According to the calculations, it will fly by Jupiter on December 2, 1974.

The Pioneer 10 and Pioneer 11 probes will forever enter the history of cosmonautics as the "first discoverers" of planets. Pioneer 10 was the first ambassador from mankind to the planet Jupiter. Pioneer 11 has been endowed with a no less honorable mission: to be the first probe aimed toward the more distant

planet, Saturn. Pioneer 11 was not originally intended to make this flight. NASA decided upon it after a detailed study of the results obtained from Pioneer 10 and of the possible variants of the Pioneer 11 program after its Jupiter flyby. Now, after the trajectory corrections made on commands from Earth, when the probe has passed Jupiter, it will take up a course toward Saturn, a planet which is no less puzzling and, perhaps, even more unusual. The outstanding peculiarity of Saturn among the planets of the Solar System is the presence of rings around it, which, until recently, were assumed to consist of very fine particles moving in satellite orbits around the planet. In 1973, American radio-astronomers performed the first successful radio location of Saturn, using for this purpose the 64 meter antenna of the space communications station at Goldstone. The results indicate that the rings cannot consist of fine crystals, dust, or gas but, rather, are "swarms" of uneven blocks of solid material, perhaps more than one meter in diameter. This /32 discovery aroused scientists to an even greater interest in the study of Saturn and its rings.

Saturn lies approximately twice as far from the Sun as Jupiter. Pioneer 11 will require about five years to cross the distance from Jupiter to Saturn. In September, 1979, it will approach Saturn, having been accelerated by the gravitational field of Jupiter. Up until 1973, a "Grand Tour" project was under development in the USA, in which a single probe would study several of the outer planets. The idea of this project arose in connection with a forthcoming unique occurrence in the Solar System, when several of the outer planets will simultaneously be in approximately the most convenient positions to be reached by space probes. Several variants of the Grand Tour were proposed. According to one, a space probe launched in 1976 - 1977 would fly past Jupiter, Saturn, and Pluto; in another, it would fly past Jupiter, Saturn, Uranus, and Neptune. The cost

of the project was estimated at 700 to 900 million dollars. However, after considering the possibility of such an expensive project, the government of the USA decided, instead, to launch two Mariner probes, weighing 750 kg, in August-September, 1977, on simultaneous flights to only two planets — Jupiter and Saturn. It is estimated that this project will cost only 360 million dollars.

In contrast to the Pioneer 11 probe, which is following a similar but more elongated trajectory, the two Mariner probes, to be launched 20 days apart, will arrive at Saturn in a much shorter time. This is due both to the use of the new Titan-Centaur booster rocket, which was developed for the Mars flight of the Viking probe, and to the specially chosen form of the trajectory, which makes use of Jupiter's gravitational field to accelerate the probes even more. Thus, although they will take off years after the launch of the Pioneer 11, the latter probe will arrive near Saturn only two years ahead of them.

The improved equipment of the Mariner series will make it possible to carry out a much more extensive research program with these probes than with the Pioneer series, including, in particular, studies of the rings of Saturn and Saturn's moon Titan, which has an atmosphere. Many foreign scientists from England, France, West Germany, and Sweden, are participating in /33 the development of the experimental program of these probes, provisionally named Mariner 77.

NASA is also working on the launch of a Pioneer probe to be put into orbit around Jupiter.

On November 3, 1973, the USA launched the Mariner 10, designed to study the planet Mercury. Mariner 10 was the first probe to carry out an investigation of this planet lying closest to the

Sun and the first to make use of another planet's gravitational field to attain such a trajectory. As we mentioned above, a similar scheme will be used in the double Mariner flight to Saturn.

On February 5, 1974, the Mariner 10 flew past Venus at a distance of 5,700 km above the surface, taking nearly 500 photographs of the cloud cover of the planet. Analyses of the photographs showed a puzzling Y shaped region in the cloud configuration, along with many other interesting details. Finally, on March 29, 1974, the probe reached a point only 720 km above the surface of Mercury. The resulting photographs showed a planet covered with many craters and very reminiscent of our own Moon.

Manned Flights

The Apollo Flights

On July 20, 1969, the ten-year-old American program to land a man on the Moon scored a resounding success. After the first lunar expedition on the Apollo 11 spacecraft, five more manned flights led to successful landings on our natural satellite.

The Moon landings of the Apollo manned spacecraft made use of an orbital docking maneuver first suggested by the Russian scientist, Yu. Kondratyuk. In this method, the spacecraft was placed in a near-lunar orbit, after which the lunar module separated from it. In the lunar module, two astronauts made a landing on the Moon and, then, after taking off from the surface, reunited with the basic Apollo unit, which remained in lunar /34 orbit with a third astronaut on board. After the astronauts transferred to the main unit, the lunar module was dropped onto the Moon, and the spacecraft returned to Earth. This maneuver

has many advantages over a direct landing, chiefly including: a reduction by 15 — 20% in the cost of the project; reduction of the time the cosmonauts must spend in flight; simplification of the problem of landing on and taking off from the lunar surface. Thus, a basic part of the construction of the Apollo spacecraft was the lunar module, which performed the landing and takeoff. The module was six meters tall and had a landing weight of five metric tons. In the center of the module was an engine with a thrust of about five tons. The module also served as a launching platform. The takeoff unit, with an engine of 1.6 tons thrust, consisted of two hermetic cylinders, 2.3 and 1.5 meters in diameter. The larger held the astronauts, together with the scientific equipment that they left on the Moon. The smaller held the navigational and communications equipment. The lunar module was joined to the main unit by means of a tunnel 80 cm in diameter, placed underneath the takeoff unit.

The main unit of the spacecraft consisted in turn of two parts, the command and service modules. Only the command module of Apollo returned to Earth. It was cone shaped (height 3.4 m, base diameter 4 m, weight 5 metric tons) and carried a rocket motor at the tip. The astronauts took off from Earth in this module and returned in it. The command module was the navigation center of the spacecraft. In its nose section were the steering, communications, navigation, computer, and indicator equipment. The system of life support and control of the internal environment maintained an atmospheric pressure of pure oxygen at 0.35 atm, the temperature at 24° C, and the humidity at 40 — 70%.

Beneath the command module was the service module, a cylinder 3.9 meters in diameter, 4.25 meters long and weighing 22 tons. /35
This contained the fuel and the service engine, with which it was possible to correct the course on the trajectories to and from Earth and to control the orientation of the spacecraft.

This engine could be turned on up to 50 times. Also, in the service module were the electrical equipment of the spacecraft and the part of the astronauts' life support system that produced their drinking water. The service module was separated from the spacecraft after the Apollo entered the dense layers of the atmosphere on its return to Earth.

The lunar module was in the adapter attached to a rocket engine. The adapter was cone shaped, 8.9 meters long, and weighed 1.8 tons. When the spacecraft was first put into orbit around the Earth, the astronauts carried out a regrouping of the modules, joining the command and lunar modules together. The Apollo spacecraft also had an emergency rescue system, which separated from the ship when the second stage rocket turned on.

The booster rocket of the Apollo spacecraft was the three-stage Saturn 5 rocket, capable of putting a 140 ton payload into Earth orbit or a 45 ton payload into lunar orbit. The first stage of the Saturn 5 comprised 75% of the starting weight of the entire rocket, which exceeded 2,700 tons. The first three unmanned spacecraft were launched into Earth orbit with the use of the two-stage Saturn 1B rocket booster, which was also used to orbit three crews of the American orbital space station. The Skylab itself was put in orbit with the help of a Saturn 5 rocket.

As the Saturn 5 rocket was improved, the scientific experiments for the Apollo 15, Apollo 16, and Apollo 17 spacecraft grew more extensive, including those to be carried out both on the Moon and, particularly, in lunar orbit. The weight of the scientific apparatus to be delivered to the Moon grew to 550 kg, and an additional module carrying scientific apparatus, called the SIM-bay, was attached to the service module.

The astronauts' life support system and the capacity of the spacecraft accumulators were also increased. During these last three expeditions to the Moon, the nose section of the craft carried a small artificial lunar satellite (weighing about 40 kg) which, by means of a spring mechanism, was put into orbit around Luna to carry out measurements of the radiation and magnetic fields and to study the mass distribution in the body of the Moon. After the end of the Apollo program, part of the craft (modifications of the command and service modules) will be used in the joint Soviet-American flight in 1975 and was used in the Skylab program. /36

Let us now take a look at all six of the Apollo lunar expeditions as they occurred.

Apollo 11 was launched on July 16, 1969, from Cape Kennedy, Florida, with millions of spectators watching. The commander of the expedition was Neil Armstrong, the pilot of the command module was Michael Collins, and Edwin Aldrin was the pilot of the lunar module. Three days after launching, the spacecraft was braked by the engines of the service module into an orbit around the Moon. One day later, the lunar module, piloted by Armstrong and Aldrin, landed safely on the Sea of Tranquillity. Six hours after the landing, Armstrong stepped out on the surface of the Moon, to be followed 20 minutes later by Aldrin. The astronauts made sure that they could easily adapt to the lunar gravity, which is only one-sixth of Earth's.

Once on the surface of the Moon, Armstrong and Aldrin first set to work with the scientific apparatus. To help scientists back on Earth study the structure of the Moon, they set up a passive seismometer to register lunar earthquakes and the shocks of meteorites striking the surface. The astronauts also set up a laser reflector. With this device, laser beams from Earth

can be reflected straight back to provide a precise means of measuring the distance between Earth and Luna. In addition, the astronauts set up a device for determining the composition of the solar wind and collected approximately 22 kg of lunar rock samples. After two and one-half hours on the surface of the Moon, Armstrong and Aldrin returned to the lunar module. /37 A few hours later, the lunar module made a successful takeoff into orbit around the Moon, where it rejoined the command module. The three astronauts returned safely to Earth and were picked up in the Pacific Ocean.

After the return from the Moon, the rock samples and the crew were placed in an isolator and quarantined for 21 days in a special laboratory in Houston, Texas. Extensive medical and biological examinations showed that no living organism had been brought back from the surface of the Moon. These precautionary measures were taken to prevent the contamination of Earth by possible dangerous micro-organisms from the Moon. The lunar rock samples were eventually distributed among 144 scientists all over the world.

The second landing on the Moon was made by a crew headed by Charles Conrad, with Richard Gordon as the pilot of the command module and Alan Bean as the pilot of the lunar module. The spacecraft was launched from Cape Kennedy on November 14, 1969. During the takeoff, the ship was twice struck by lightening, which caused some disturbances in the spacecraft systems. When the ship reached Earth orbit, the crew checked out the electrical system and apparatus without finding any significant damage.

Approximately three days later, the spacecraft entered an orbit around the Moon. On November 19, 1969, Conrad and Bean landed the lunar module on the surface of the Moon, about 180 meters from the old Surveyor 3 probe.

The Apollo 12 crew made two trips out onto the lunar surface. The first was primarily to set up the equipment for the Apollo experiments and to collect rock samples. The scientific equipment was designed for five experiments that were supposed to transmit information to Earth for at least a year. The experimental station had a nuclear energy source and a self-contained radio transmitter and receiver. The experiments could be controlled and calibrated by radio commands from scientists on Earth. The equipment included a passive seismometer to measure vibrations of the lunar surface, a device to measure the density of the /38
lunar atmosphere, a magnetometer to measure the magnetic field, a mass spectrometer to measure the velocity and amount of protons and electrons in the solar wind, and a device to determine the amount of lunar dust.

The second excursion on the Moon lasted 3 hours and 49 minutes. In this time, the crew again collected lunar rock samples, took many photographs, and checked the condition of the Surveyor 3 probe, which had been sitting on the Moon for nearly two and one-half years. Together with the rock samples, the astronauts took a part of the Surveyor 3 back to Earth for scientific study.

After takeoff from the Moon and reunion with the command module in orbit, the lunar module was jettisoned onto the Moon to test the calibration of the seismometer. The shock caused a 55 minute vibration of the soil that was recorded on Earth.

The crew returned safely to Earth and splashed down in the Atlantic Ocean. Again the astronauts were quarantined for 21 days, and again the medical and biological studies showed that no life forms exist in lunar material. The Apollo 12 expedition can be considered, unconditionally, a great scientific achievement.

The third expedition nearly ended dramatically and did not succeed in landing on the Moon. It was commanded by James Lovell; John Swigert was the pilot of the command module, and Fred Haise — of the lunar module.

Apollo 13 was launched from Cape Kennedy on April 11, 1970. During the launch, the central engine of the second-stage of the Saturn 5 booster cut off early, so that the remaining four engines had to work for longer than their set time. This first complication was not considered serious, and the spacecraft continued its flight to the Moon. About four hours after the launch, the command and lunar modules were joined together.

Approximately 56 hours into the flight, the crew radioed that a warning signal was ringing in the command module and that muffled explosions could be heard. Some minutes later they noted a gas leakage from the service module and, also, that oxygen was leaking from one of the tanks and that the pressure was dropping rapidly in the second tank. These reports from the crew indicated an emergency situation in the command /39
module of the spacecraft. The oxygen needed to maintain the life of the crew and to supply the fuel cells that produced electricity was rapidly running out.

This was the most serious emergency that had ever occurred in manned space flight, since the crew was en route to the Moon and could not return to Earth in less than four more days. The spacecraft crew and the ground control group quickly took emergency measures. It was decided that the lunar module, left untouched by the disaster, would be used as a "lifeboat." The life support system of the lunar module was used for the crew, and its batteries provided the energy needed for communications and to operate the navigation system. The braking engine of the lunar module was used for the maneuvers needed for the entire

spacecraft. At the start, the lack of oxygen, electrical energy, and water became an important problem. The NASA specialists worked out emergency procedures to reduce the expenditure of these vitally necessary resources. Special technical measures to improve the life support for the spacecraft crew were tested on Earth and, then, suggested to the astronauts.

Apollo 13 curved around the Moon, making use of the lunar gravitational field to aim back toward Earth. This maneuver required less energy expenditure than a sharp turn at the moment when the emergency was noticed. The Apollo 13 crew returned safely to Earth on April 17, 1970. The astronauts remained in the lunar module up until the moment of entry into the Earth's atmosphere; they then entered the command module, which was the only part of the ship designed for re-entry, and jettisoned the lunar module. The astronauts splashed down successfully in the Pacific Ocean, 6.5 km from the ship specially dispatched to pick them up.

The photographs taken by the Apollo 13 astronauts showed that a large panel of the service module had been torn away by the explosion in the oxygen tank. A commission was named to investigate the causes of the disaster; it reported that the emergency was "the result, not of an accidental failure....but rather of an unusual combination of errors that coincided with /40
several defects in construction." It was established that, during the ground tests before the flight, an overload caused an electric arc that melted and shorted out a switch. After this, it no longer operated as a thermal safety cutoff, as a result of which the temperature in the heating system of the tank rose, probably, above 540° C. This overheating damaged the insulation of the ventilator motor and short-circuited its windings, in addition to the burning due to the electric arc. The final

result of this was the ignition in the oxygen tank that caused the explosion.

After the disaster in the Apollo 13 spacecraft, significant changes were made in the construction of the oxygen tanks in the remaining ships of the Apollo series. In addition, a third oxygen tank was installed in the service module of Apollo 14 to provide an independent oxygenreserve in case of similar incidents in the future. Because of the disaster on Apollo 13, the next expedition to the Moon was delayed for nearly six months.

Apollo 14 was launched, finally, on January 31, 1971, from Cape Kennedy, and took part in the third successful landing of an American spacecraft on the Moon. The crew commander was Alan Shepard, who in 1961 was the first American to be launched into space; Stuart Roosa piloted the command module, and Edgar Mitchell — the lunar module. The purpose of the flight was to investigate the mountainous region of the Moon and to try to find matter that could have formed part of the ancient lunar crust or of its surface layer before it was scattered over the entire surface of the Moon by meteorite impacts.

After the third-stage engine of the rocket booster was turned on, the spacecraft picked up enough speed to leave Earth orbit and begin its flight trajectory to the Moon. The crew encountered their first difficulty in the attempt to join the command and lunar modules. After the first docking attempt by Roosa, the docking pin failed to lock into the receiving cone, which was necessary for the secure joining of the two modules. This led to serious difficulties, since the docking mechanism must work perfectly to permit the crew to transfer to the command module after performing their tasks in the lunar module. /41
When the docking was finally accomplished, the astronauts examined

the mechanism and came to the conclusion that the flight could be continued without danger. Three days after the launch, the velocity of the spacecraft was reduced to put the ship into orbit around the Moon. On February 5, 1971, the lunar module separated from the command module and made a successful landing in the planned region of the Moon. While Roosa continued to orbit around the Moon in the command module. Shepard and Mitchell made two trips onto the lunar surface. The astronauts remained on the Moon for a total of 33.5 hours. During their first excursion, the astronauts set up five scientific devices on the Moon. These devices were to permit scientists to study the seismic activity of the Moon, to detect particles in the lunar atmosphere, and to investigate the structure of the lunar interior. Shepard and Mitchell also placed a laser reflector on the surface of the Moon.

During their excursions on the Moon, the astronauts used a two-wheeled trolley to carry the scientific equipment from place to place on the surface. The purpose of the second excursion was to study the mountainous region in the vicinity of Cone crater and to collect soil samples.

Shepard and Mitchell spent about 9.5 hours in studying the region where the spacecraft landed, not far from the Fra Mauro crater. Then, with the help of the takeoff stage of the lunar module, the astronauts returned to orbit and docked with the command module piloted by Roosa. The crew made a safe return flight to Earth and splashed down in the Pacific Ocean on February 9. Then, the crew members, the lunar rock samples, and the spacecraft itself were taken back to the Manned Space Flight Center in Houston, Texas, for quarantine.

On July 26, the Apollo 15 took off from Cape Kennedy for a flight on which the scientists placed great hopes. The commander

of the crew was David Scott, the command module pilot was Alfred Worden, and the lunar module pilot was James Irwin. The space- /42
craft launch and the subsequent rearrangement and docking of the command and lunar modules came off without a hitch, not counting a faulty switch on the computer control panel which was replaced by a hand switch during the flight. The trip to the Moon followed the scheduled program; on July 30, the lunar module, carrying Scott and Irwin, separated from the command module and landed at the foot of a mountainous ridge near the deep Hadley canyon.

During their 67-hour stay on the Moon, Scott and Irwin made three excursions onto the lunar surface. On these trips, the astronauts traveled by means of a 190 kilogram four-wheeled vehicle. The excursions lasted 18 hours 37 minutes, in which time the astronauts covered 28 kilometers, collecting samples of the lunar rocks and photographing the canyon and the mountain ridge. On the slope of the mountain, they found a crystalline rock, which the scientists think may be a sample of the ancient lunar crust. Scott and Irwin set up experiments alongside the lunar module, similar to those on Apollo 14.

On August 2, Scott and Irwin left the Moon carrying 70 kg of lunar rocks. Before beginning the return trip to Earth, they set an artificial satellite in orbit around the Moon. During the return flight, Worden left the command module and "walked" in space, in order to recover a film from the system of photocameras that had been taking pictures of the Moon during the flight of the command module. On August 7, Apollo 15 completed a safe splashdown in the Pacific Ocean.

The launch of the Apollo 16 spacecraft took place on April 16, 1972, from Cape Kennedy, after a month's delay due to various technical defects. This was the fourth space flight for the crew commander, John Young, but the lunar module pilot, Charles

Duke, and the command module pilot, Thomas Mattingly, were novices in space. The first part of the flight and the entry into lunar orbit went off as programmed, despite a few insignificant deviations caused by minor troubles with the third stage of the booster rocket.

The first significant trouble encountered by the expedition arose in orbit around the Moon, after the separation of the modules in preparation for the descent to the Moon. It was /43
found that the backup engine yaw control system was not working properly. Tests and analyses showed, eventually, that the system was working within normal limits; however, the landing on the Moon was delayed for six hours.

The landing area of the 11-day expedition was 72 km north of the ancient Descartes crater on the broken, hilly edge of the Kant plateau, in the center of the mountainous part of the Moon and among the highest peaks on its surface. This region was of particular interest to geologists, since it was believed that samples of dirt and mountain rock from this region would add to our knowledge of volcanic activity and its role in the evolution of the Moon. Near the landing zone were two large craters, North Ray and South Ray.

Astronauts Young and Duke made three excursions onto the surface of the Moon. During the first trip, they unloaded from the lunar module, a vehicle with an electric motor and put it in working order. The astronauts set up on the Moon an ultraviolet spectrograph for the first astronomical observations. With this device, they took photographs of the Earth, the galaxies, and the Magellanic Clouds. The scientists also hoped to use these photographs to study the atmosphere and magnetosphere of Earth and their interaction with the solar wind. From this experiment, the value of Luna as a possible platform

for astronomical observations could be estimated. During the first excursion on the Moon, the astronauts fitted out two lunar research stations near the craters Flag and Spook. During the second excursion, they carried out geological researches and collected samples of lunar soil on Stone Mountain and in several craters. During the third excursion, the astronauts traveled to the rim of North Ray crater and investigated the region in detail, taking many rock samples and photographs.

In all, the astronauts spent 20 hours 14 minutes studying the Moon; they traveled about 27 km and collected about 80 kg of soil and mountainous rock samples.

After 71 hours on the surface, the astronauts took off in the lunar module and successfully approached and docked with the command module. The expedition ended one day earlier than had been planned. The spacecraft returned to Earth and splashed /44
down in the Pacific.

Apollo 17 was launched on December 7, 1972. The crew of the spacecraft included Eugene Cernan (commander), Ronald Evans (command module pilot), and Harrison Schmitt (lunar module pilot). This flight was the last in the Apollo program. The chosen landing area was in the Taurus-Littrow region, in the northeastern portion of the Moon's disc on the southeastern edge of the Sea of Serenity. The rocks of this region are assumed to be pieces of the lunar crust in mountainous form, having arrived there as a result of the faults and emissions accompanying the formation of the basin of the Sea of Serenity. The third member of the expedition, Harrison Schmitt, became the first astronaut-scientist, a specialist in geology. He is the only geologist ever to have reached the Moon.

During this expedition, an unexpected discovery was made near the crater Shorty. While traveling in the lunar rover, Cernan suddenly spotted a patch of orange soil. In the opinion of Schmitt, announced while he was still on the Moon, this orange soil bore witness to some recent volcanic activity in this region of the lunar surface. A laboratory analysis of the orange soil samples performed on Earth showed that it is composed 90% of glassy particles in spherical shape. The colors of the spheroids in the sample varied from yellow-orange to red-brown and even black tones. The orange color of the glassy particles is probably due to a high content of titanium oxide. No signs of water were found. Careful studies of the orange soil samples led the NASA specialists to believe that they were formed by the melting of the surface material at the instant of supersonic impact. Dating of the orange soil gave an age between 3.63 and 3.69 billion years, which also fails to agree with the hypothesis of recent volcanic activity. At the same time, while flying over the Moon in the command module, Evans observed a puzzling flash in the vicinity of the Copernicus crater. The seismometers /45
recorded no meteorite falls at that instant. It is suggested that the flash was due to gas emission from the depths of the surface near Copernicus, which would confirm the possibility of volcanic activity on the Moon.

The Skylab Orbital Space Station

The first American orbital station, Skylab, was a modified form of the third stage of the Saturn 5 rocket. It had a length of 14.6 meters (36 m in expanded form) and a diameter of 6.5 meters. The volume of space inside the station filled with artificial atmosphere was more than 300 cubic meters. The weight of the Skylab station delivered into orbit was 80 metric tons. The station consisted of a laboratory and living quarters, in which most of the astronaut activities took place, plus a module

containing an optical telescope and a joining module used for docking by astronauts arriving on the modified Apollo spacecraft. The spacecraft had no lunar module. In contrast to the pure oxygen atmosphere on earlier American manned spacecraft, Skylab was supplied with an oxygen-nitrogen atmosphere (70% oxygen, 30% nitrogen) at 0.35 atm pressure. The temperature inside the station could be controlled by the astronauts themselves between the limits of 10° and 32° C. The energy supply of the Skylab consisted of a complex of solar and storage batteries (where the latter are recharged by the former).

The laboratory and living sections were surrounded by an antimeteor screen, a break in which nearly led to the collapse of the entire Skylab program. The laboratory section, 6 m long and 6.5 m in diameter, was designed to allow the crew to carry out the various experiments scheduled. The living quarters provided space for sleep, food preparation and eating, personal hygiene, and leisure activities. The astronauts had a small library of books and music, a large porthole with a view of Earth, a hot shower, and a regular telephone connection to Earth. All the fittings of the station and the equipment needed for the activity of all three crews was present onboard the Skylab at the time it was launched. This included 907 kg of food in frozen and dried form, and 2,722 kg of water. The Skylab was built by NASA in a relatively short time and at a relatively low /46
development cost. The cost of the entire Skylab program is estimated at 2.5 billion dollars.

It was planned for the first crew to stay at the station for four weeks and the other two crews for eight weeks each (it was later decided, however, to extend the stay of the third crew to twelve weeks). A large number of studies and experiments were to be carried out by the Skylab crews, including: 1) biomedical studies to determine the effects of space flight on

humans and animals; 2) Earth observations to investigate natural resources and to monitor harvest growth and the spread of plant diseases; 3) studies of material properties and technological processes in conditions of weightlessness and vacuum (welding, mixing, etc.); 4) solar studies; 5) astrophysical studies; 6) various engineering and technical experiments in space to define the requirements of future orbital stations. For various reasons the principal experiments for each of the crews turned out to be the following: biomedical for the first, solar studies for the second, and studies of Comet Kahoutek for the third. In addition, the first crew and, to some extent, the second crew were occupied with unexpected repairs to the station.

The launch of the Skylab station was planned for April 30, 1973, and the first crew was to take off a day later. These plans were first threatened by a strike by workers at the launching complex, whose demands were satisfied very quickly. Troubles then appeared in the system of apparatus to be used for studying Earth resources, which led to a two-week delay in the launch of the station. On May 14, 1973, a Saturn 5 rocket put the first American Skylab orbital station in orbit around Earth at a height of 435 km. Less than an hour after takeoff, however, the first malfunction was detected: despite several attempts to turn on the system for opening two of the four solar battery panels, the latter failed to open. Some time later, a second /47
malfunction was observed: the temperature inside the station began to rise catastrophically, quickly reaching 50° C. A further rise in temperature could have led to the collapse of the entire Skylab program, since, even at this temperature many medications and some items of food would be ruined. The temperature rise threatened to reduce the structural integrity of the station and to damage the sensitive electronic equipment on board. Finally, under these conditions, the plastic lining of the station would emit poisonous gases that would endanger

the lives of the astronauts, who were supposed to work without spacesuits. What had happened?

It was discovered later that when the station was 63 seconds into its flight, an uneven distribution of pressure under the meteor screen caused the latter to break away from the station, completely destroying one of the solar battery panels and jamming a second on one of the bolts by which it was attached to the station. Since this screen, made of aluminum foil 0.6 mm thick, was also supposed to reflect solar radiation, its failure led to the rapid heating of the station.

Thus, the Skylab was lacking half of its energy supply and was become greatly overheated. It was decided, first of all, to prevent further heating of the station. It was, accordingly, rotated to present a smaller surface to the Sun. However, this led to excessive cooling of the dark side of Skylab, which could cause the water on board to freeze and burst the tanks and pipes in which it was stored. To balance the temperature, the orientation of the station with respect to the Sun had to be altered from time to time.

Because of the emergency on the Skylab station, the launch of the first crew was delayed for a week, and some NASA specialists felt that no astronauts should be sent to board it. However, after working out a repair program, NASA decided to try to correct the existing situation. Shortly before the takeoff of the astronauts to reach the station, a sharp rise of the station temperature to 88° C was recorded. The launch was put off again and did not take place until May 25, 1973.

The first crew of the Skylab can rightfully be called a "rescue expedition." The astronauts were Charles Conrad, Joseph /48
Kerwin, and Paul Weitz. For Conrad, the crew commander, this

was the fourth time in space. He was a graduate of Princeton University and had been an astronaut for eleven years. He was also the third man to walk on the surface of the Moon. Weitz was a graduate of the University of Pennsylvania and had a Master of Science degree. Finally, Kerwin had a medical education. They were to try to save Skylab, and they succeeded.

One hour after launching, the Apollo spacecraft approached the Skylab station, and, for the next hour, they flew around it sending back television pictures of its exterior. They then docked with it, but the flight director decided to try to extend the solar battery panel directly from space. However, an attempt by Weitz to free the jammed panel with the help of a special hook ended unsuccessfully. When the spacecraft returned to the docking module of the station and attempted to dock with it again, the first six attempts failed. It was later found that this was the result of a short circuit in the docking system. Eventually, the cabin of the Apollo was depressurized and one of the astronauts went into open space and made use of the emergency hatch on the Skylab to correct the docking mechanism. The following attempt at docking was successful, and the tired astronauts were able to rest in the cabin of the Apollo.

The next day the crew, wearing respirators but no suits, entered the Skylab station. Detectors brought from Earth discovered no traces of poisonous gases. The main problem of the day was to set up a heat screen in order to lower the temperature inside the station. Within five hours, working in the hottest part of the station where the temperature reached 51° C, the astronauts managed to set up the screen. When the screen was set up, it was found that it could not be fully extended. However, the temperature of the station began to drop. The crew again returned to rest in the Apollo spacecraft

after opening all the internal hatches of the station to allow free circulation of the air. The third day was spent in testing the scientific equipment; the first television transmission was made from the station to Earth. The temperature inside Skylab /49 had dropped to 36° C. The astronauts were already sleeping inside the station itself but in convenient hammocks set up beside the docking module. On the fourth day, the testing of the station equipment continued, and the temperature dropped to 31° C. Only on the fifth day could the crew begin to carry out the planned scientific experiments and to use the full power of the station batteries (4.6 kW). The temperature fell to 29.5° C. On the following day, the two storage batteries of the station went out of order, which threatened to bring a halt to the planned research program. During the whole of the seventh day, the astronauts took instructions from Earth on how to get rid of the fragments of the meteor screen that were jamming the solar battery panel. The problem was that no such situation had been foreseen in the planning of the station, so that there were no supports on the outside of the station to which the astronauts could attach themselves in order to work safely without the risk of drifting off into open space. The exit from the station and all the corresponding operations were carefully rehearsed on Earth by the commander of the first backup crew, Russell Schweickart. The next day the crew rested. The temperature dropped to 27.5° C. In the following days, the astronauts successfully carried out experiments and managed, almost, to catch up to the research schedule that had been delayed by the repair work. On the twelfth day, the temperature dropped to 24.2° C. On June 7, 1973, Charles Conrad went out into space to try to extend the solar battery panel. Holding onto an improvised handrail, one end of which had been attached to the body of the station near the panel, Conrad approached the panel carefully, using shears to cut loose the scraps of screen and the bolt that was jamming it. The panel was "saved." This

space walk was shown on television. Kerwin helped him, remaining in space near the exit hatch. Weitz stayed inside the station. The job took one and one-half hours. The newly extended panel helped raise the energy supply of the station to 80% of the originally calculated value. For the first time, the astronauts could allow themselves to heat their food and take a hot shower. In the following days, they continued to carry out the program of scientific experiments, primarily the /50
observation of the Sun with the help of the system of astronomical apparatus. On June 15, the astronauts managed to observe from the very beginning the development of a flare on the Sun. During the next few days, a valve in the cooling system unexpectedly went out of order. At the beginning of the 26th day, Conrad again went out into space, but, this time, is was part of the planned program of the flight. After changing the cassettes in the astronomical equipment, he "repaired" one of the storage batteries by striking the voltage regulator with a hammer. And the battery began to work! On the 27th and 28th days of the flight, the astronauts spent their time packing away the equipment.

Despite the necessary repair work, the first crew completed 87% of the planned solar studies, taking 30,242 photographs of the Sun, and 90% of the medical experiments. They also carried out 88% of the Earth studies program and warned meteorologists on Earth about the growth of the hurricane Ava. On June 22, the crew returned to the Apollo spacecraft, took leave of the station, and started back to Earth. After the splashdown in the Pacific Ocean, the Apollo was lifted onto the deck of the aircraft carrier sent to meet them. Complete readaptation to terrestrial gravity took Conrad only two hours, while Weitz recovered in eight hours and Kerwin - not until the second day.

On June 24, Richard Nixon, the President of the USA, took the astronauts to his California residence and presented them

to L. I. Brezhnev, the General Secretary of the Communist Party of the Soviet Union, who was in the United States on an official visit. The astronauts asked Brezhnev to give to the Soviet cosmonauts a knife that they had used on the flight. On it was engraved: "We are with you as you are with us on all space flights."

The flight of the first Skylab crew was a remarkable achievement in American astronautics. During their flight, they almost completely repaired the station and made it possible for the rest of the Skylab program to be carried out completely. However, while the station was left empty, several gyroscopes in the stabilization system went out of operation, and the cooling system, which had failed several times during the flight of the /51 first crew, did not maintain the necessary temperature. For this reason, the flight program of the second crew had to include replacement of the faulty gyroscopes with new ones and the installation of a new, more efficient heat shield. The shield, the new gyroscopes, and the various animals for the biological studies (flies, spiders, mice, fish) increased the weight of the Apollo spacecraft for the second crew to 500 kg more than the first.

The crew commander, Alan Bean, had accompanied Conrad, the commander of the first crew, in walking on the Moon during the Apollo 12 expedition. The other members of the crew, Jack Lousma and Owen Herriot, were novices in space. Since the principal task of the second crew was to be solar observations, the crew included a specialist in solar physics, Owen Herriot. On July 28, 1973, an Apollo spacecraft took off with the second crew on board. Like the first crew, they first examined Skylab from the side, transmitting television pictures back to Earth and then proceeded to dock successfully. The following days were spent in unpacking the station equipment and preparing for

the experiment in replacing the heat shield. The exchange, planned for July 31, was to be carried out in open space. However, again the unforeseen occurred.

Immediately after settling into the station, the astronauts began to suffer from "seasickness." Particularly after eating, they experienced headaches, disorientation, and nausea. All the work began to lag far behind schedule. The space walk was put off; but the state of the astronauts did not improve. They were given an extra day of rest. It was later decided that the deterioration in the condition of the astronauts was caused by the very abrupt movements that they made in the open space of the station, having no entry area to permit gradual adaptation.

A second problem arose quickly. When the astronauts had just begun to feel a bit better, a failure occurred in the second oxidizer tank in the Apollo engine system. The first tank had begun leaking even as the Apollo approached the station. If even one more tank went out of operation, the astronauts /52
would not be able to return to Earth in that spacecraft. The NASA specialists feared that this was precisely what might occur, suspecting that there could be a corrosive impurity in the oxidizer that could cause the failure of the entire engine. It was decided, however, to leave the astronauts, who by this time had lost almost all symptoms of "seasickness," in orbit, but to prepare an Apollo rescue craft for immediate takeoff. The preparation of the Apollo rescue ship went on around the clock, but even at this accelerated rate, the spacecraft could not be ready to take off before September 10.

Meanwhile, the second Skylab crew had "recovered" from their illness and were trying hard to catch up to the schedule. The daily quota of scientific experiments was raised by 50%. In fact, they even complained that the preparation of food and other

"domestic" tasks took up too much of their time. However, they soon got used to this way of life. On Sundays, when the program called for the astronauts to rest, they decided to carry out further experiments.

On August 6, Lousma and Herriot went out into space to set up the new heat shield. This time the commander of the crew remained inside the station. Instead of the three hours envisaged by the original schedule, they spent six and one-half hours on the task, but, unlike the astronauts of the first crew, they succeeded in opening the shield to its full extent. After this, the temperature in the station remained close to its optimum value (21° C).

Most of the working time of the second crew of astronauts was taken up by observations of the Sun. In all, there were 305 hours of observations instead of the planned 200 hours. During this time, the Sun was very active. Several strong flares on the Sun were recorded, and some large groups of sunspots were observed. On August 31, an experiment with "flying shoes" was carried out for the second time; this involved a test of a system of microjets mounted on the astronauts' boots for movement in open space. A "technological" experiment was also /53
carried out. In essence, two crystals were first melted in an electric oven and then allowed to stand and harden. The purpose was to determine the possibility of improving the quality and chemical homogeneity of the crystals obtained in the weightless conditon. Studies of the Earth's natural resources were carried out regularly during the flight. And, again, the crew exceeded the experimental program; they carried out 39 observational periods instead of the planned 26. At the end of August and the beginning of September, the astronauts detected and observed the growth of the tropical hurricanes Christine, in the Atlantic Ocean, and Delia, in the Gulf of Mexico. The observations

of natural resources were also carried out over the countries of Western Europe, Japan, Australia, West Africa, and Central and South American. In accordance with agreements reached earlier, the results of these observations were placed at the disposal of the governments and scientific organizations of these countries.

Unfortunately, the biological experiments were largely unsuccessful. As a result of a failure in the life support system, the mice and fruit flies died. The fish could not get used to weightlessness and never learned to swim in a straight line. However, the two female spiders, Anita and Arabella, in spite of the lack of gravity, began after some moments of confusion to spin geometrically correct webs. Although feeding of the spiders was not planned in the experiment, it was decided to feed them with pieces of beef, so that they could return to Earth alive. However, only Arabella managed to return alive from space. To commemorate this feat, an emblem bearing a picture of Arabella was placed in the office of the Manned Space Flight Center in Houston.

While the astronauts carried out their researches on board the Skylab, preparation of the Apollo rescue ship continued on Earth, but at a slower tempo, to be ready on September 24, a few days before the planned ending of the astronauts' stay on the orbital station. Some tension also arose on the Skylab when a few more of the stabilization system gyroscopes went out of operation. However, by the time of the second space walk on August 24, the astronauts had installed the reserve set of gyroscopes brought from Earth. At this time, as well as during the third space walk (September 22), the astronauts of the second crew changed the cassettes in the astronomical equipment /54
and took samples of various materials and coatings from the body of the station on which they were exposed, in order to return them to Earth.

When it came time for the return to Earth, there still remained doubts about the reliability of the remaining oxidizer tanks for the Apollo engines. On September 25, after carefully repacking the station equipment, the second crew re-entered the Apollo spacecraft, undocked, and started on the return path to Earth. On the night of September 26, they splashed down precisely in the planned region. Even at the very last minute, the astronauts were unlucky. The spacecraft impacted the water unexpectedly and landed bottom up, but by filling three special balloons with gas, they turned the ship to the normal position. In contrast to the first crew, the astronauts of the second crew had worked out assiduously on an exercise bicycle on board the Skylab, so that they readapted to terrestrial gravity very quickly, even more quickly than the first crew, although the flight had lasted twice as long. The second crew, having spent eight weeks in space, had duplicated almost to the minute, the record of time spent in space set by the Soviet orbital space station "Salyut."

After the return of the second Skylab crew to Earth, it was decided to have the third crew remain three months in space. It was necessary, therefore, to add some food to the stock of the Skylab, as well as some of the coolant used in the cooling systems of the equipment on board. In order not to overload the Apollo spacecraft, high calorie products were selected.

On 16 November 1973 the third crew arrived at Skylab. All the astronauts, including the commander Gerald Kapp, were novices in space. The oldest of them, at 43, was the second pilot William Pogue; the youngest 37 but, already a Doctor of Science, was Edward Gibson, a specialist in physics. As they entered the station, the third crew was greatly surprised to find "people" there in the uni- /55
forms of American astronauts. These proved to be scarecrows left there as a surprise for them by the astronauts of the second crew. However, the new Skylab crew was in no mood to laugh. From their first days on board, the third crew of the Skylab station remained in an apathy incomprehensible to the NASA specialists. They did

not complain about their health, but all their actions were slow; they always lagged behind the schedule and were very tired. They hardly spoke at all and never joked. According to the NASA specialists, this "lethargy" may have been due to the individual peculiarities of the astronauts.

The principal task of the third Skylab crew was to observe the Comet Kohoutek. For this purpose, they used five different instruments that were part of the astronomical equipment of the station. In addition, the astronauts observed and photographed the Comet directly during two space walks. While the Comet was still at a large distance from the Sun, the astronauts photographed it in the optical and ultraviolet bands of the spectrum. As the Comet approached the Sun, they observed it with the system of telescopes designed for solar studies. Many interesting results were obtained from these observations, and approximately 75,000 photographs were taken of the Comet and the Sun. For the first time, an interesting effect was observed in which the sunlight reflected from the Comet formed a sort of second tail directed toward the Sun.

Besides the astronomical studies, the program of natural resource studies was continued, and about 20,000 photographs of the Earth were taken from the Skylab station. In particular, regions of cold water up to 65 km wide were detected in warm ocean currents. All this research was sharply affected by the "energy crisis" that afflicted the astronauts on board the Skylab. The problem was that the reserves of compressed nitrogen had undergone heavy use during their time in orbit. Then when /56
the power gyroscopes (which should not be confused with the gyroscopes of the stabilization system) went out of order, the reorientation of Skylab to carry out scientific studies had to be sharply cut down. For this reason, the number of experiments to study Earth resources was also cut down.

The astronauts returned to Earth on February 8, 1974. During their stay on Skylab, they had walked in space four times, completed 1,214 orbits around the Earth, and set a record for time spent in orbit, which now stands at 84 days,/1 hour, and 16 minutes. All the crew members readapted very quickly. Kapp had even gained weight. As a result of their long stay in weightlessness, the height of the astronauts increased by two to three centimeters.

The program of the first American space station, Skylab, ended with the return of the third crew to Earth. On February 9, 1974, the electrical supply system of the station was turned off,and the station activity was shut down. According to NASA estimates, the Skylab will remain in orbit for seven to ten years before it enters the dense layers of the atmosphere.

Joint Soviet-American Flight

On July 15, 1975, at 3:30 p.m. Moscow time, a "Soyuz" spacecraft will be launched from the USSR with two cosmonauts on board. Thus, will begin a great cosmic experiment in which, for the first time, representatives of the two space powers will meet in space. The joint flight of the "Soyuz" and Apollo spacecraft is intended to test a unified docking system. In this flight, the means of meeting in space will be worked out and compatibility tests of the docking system will be made, together with a number of scientific experiments. The introduction of a unified docking system on American and Soviet manned spacecraft will make it possible for a spacecraft from one of the countries to help a spacecraft from the other in case of a disabling emergency. Such a situation arose, for instance, at the time of the disaster on the Apollo 13, whose flight nearly ended in the death of the astronauts. In the tradition of expanding cooperation between the USSR and the USA in space /57

research, the unified docking system and the experimental joint flight of spacecraft from the two countries were planned.

During the first day after the launch of the Soviet ship "Soyuz," a number of maneuvers will be performed to place the spacecraft in an orbit 230 km high, which is convenient for docking with the American ship. The Apollo spacecraft, with three astronauts on board, will be launched 7.5 hours after the "Soyuz," and, then, 21 hours after the Apollo launch, the two craft will meet in orbit. If for some technical reasons, the takeoff of either ship is slightly delayed, a number of additional "windows" have been designated for the launch of both ships.

After the joint flight and docking program has been completed, both spacecraft will continue independent research programs, including a number of scientific experiments. In preparation for the "Soyuz"-Apollo joint flight, six astronauts from each country have already been selected. Brigadier General Thomas Stafford has been named commander of the American Apollo crew. This will be his fourth space flight; in particular, as the commander of the Apollo 10, he directed the dress rehearsal of the first manned Moon landing. The pilot of the docking module will be Donald Slayton, a man with a most surprising history, reminiscent of that of our famous flyer-cosmonaut Vladimir Komarov. Slayton was the commander of the first group of astronauts (for the flights of the Mercury spacecraft) but lost his place in the group because of bad health. And then, like the Soviet cosmonaut, he rejoined the group, although not until ten years later. At the time of the joint flight, he will /58
be over fifty years old.

The pilot of the basic module will be Vince Brand, for whom, like Slayton, this will be the first time in space. The backup crew includes Alan Bean, Donald Evans, and Jack Lousma, none of

them novices in space. The preparation for the flight and joint training of the astronauts is taking place in both the USSR and the USA.

Space Transports

Colonization of the Moon can become a reality only when an economical system of transportation between it and the Earth has been developed. The Saturn 5 rocket, which started the astronauts of the Apollo spacecraft on their way to the Moon, is too expensive to use for the constant communication required even in the earliest stages of colonization. The Saturn 5 is a single-use rocket; after it has fulfilled its task of putting the Apollo on the proper trajectory to the Moon, its mission is ended. Its first two stages drop back into the atmosphere and burn up, while the third stage either crashes into the Moon or continues an endless flight in orbit around the Sun.

It is quite obvious that to use this rocket for the research that will be needed from the very beginning of a permanent lunar colony would be too expensive to be satisfactory. To use the Saturn for this purpose would be as senseless as scrapping a new car after its first trip.

There are other ways of developing a more economical system. However, it will hardly be possible in the near future to construct a universal spacecraft which can take off from Earth, go into Earth orbit or directly into a trajectory to the Moon, then go into an orbit around the Moon and, finally, descend to its surface and still have enough fuel to cover the return trip to Earth.

Some idea of the inefficiency and fantastic cost of such a ship can be gained by recalling that the Apollo 11 flight cost /59

375 million dollars. One single-use Saturn 5 rocket costs 185 million dollars, and the rocket and the Apollo spacecraft burned up about 2,400 tons of liquid fuel costing, by the most conservative estimate, $165,534.00. This was the quantity of fuel required to put a crew weighing 200 kg on the Moon and then to return them to Earth together with 26 kg of rocks and films.

The system proposed by NASA and the aerospace industry consists of a number of specialized spacecraft, some of which would remain permanently in space, never touching either the Moon or the Earth. The principal economy of the system lies in the possibility of multiple use. Multiple use spacecraft could fly schedules between Earth and Earth orbit, between Earth orbit and lunar orbit, and between lunar orbit and the Moon. Some idea of the economy available from the use of one type of multiple-use ships can be obtained from the estimates of George I. Muller, former assistant director of manned space flights. Speaking of multiple use spacecraft to be operated between Earth and Earth orbit, he stated: "This would reduce the cost of a flight to orbit and return to Earth from 2,500 dollars for a one-way flight at present (1970) to between 165 and 410 dollars, for each meter of the entire trip (there and back)." However, in considering the new type of spacecraft, we must also take into account the cost of its development. Leroy I. Day, the director of the special commission for the development of shuttle craft at NASA, has stated that the cost of such craft would vary between 5 and 6 million dollars, but, if we include inflation, a more realistic number would be 8 million dollars (to develop /60
five of the planned ships). Day also assumes that the construction of the additional ships over and above this program would cost 200 million dollars each, which somewhat exceeds the cost of the Saturn 5.

Another feature of this program is its universality, i.e., the development of the minimum number of spacecraft and engines for the maximum number of purposes and applications. For example, either a standard module or a living module can be mounted on the ship for takeoff, and depending on this, the craft can be used either as a space taxi or a space freight carrier, for both Earth and lunar orbits.

The development of a complex system will undoubtedly begin with the construction of shuttle transports. In December, 1968, at La Jolla, California, the NASA Scientific and Technical Consulting Committee for Manned Space Flight was set up to study the use of space flights for scientific and technical purposes between 1975 and 1985. Based on the proposals of this committee and a series of experiments to determine the technical capabilities of the industry organized by NASA in a number of aerospace companies, recommendations were made for the construction of shuttle transport spacecraft. On September 15, 1969, this recommendation was sent to President Richard M. Nixon. Vice-President Spiro T. Agnew then, as chairman of the special commission on space research, presented to Nixon a report on the planning of space research after the Apollo program. In particular, this report proposed "the application of multiple use chemically fueled space transports to operate between Earth and Earth orbit like airliners."

It later appeared that the shuttle transport will be more like a modern giant jet liner than a rocket such as the Saturn 5 or the Titan 3C. More precisely, it will look like a huge jet airplane mounted on the top of an even larger airplane. This two-stage craft will consist of a takeoff stage and an orbital stage and will be capable of vertical flight.

The shuttle transport will have a starting weight of about /61 two thousand tons. The fuël for the twelve rocket engines mounted on the takeoff and orbital stages will be liquid oxygen and liquid nitrogen. Each engine will provide a thrust of 220,000 kg, which is twice the thrust of the J-2 engines used on the second and third stages of the Saturn 5. In contrast to the Saturn 5, the engines of the shuttle craft will be constructed in such a way that they can be controlled. Thus, the climbing acceleration will not exceed 3 g's (three times the force of gravity on a body on the surface of the Earth). Accordingly, the passengers in the shuttle craft will experience an acceleration less than half of that endured by the Apollo astronauts. During the takeoff and the first minutes of the flight, the two members of the crew of the orbital stage will have little to do. The shuttle craft will be controlled by the crew of the takeoff stage, which also consists of two men.

At an altitude of about 69 km, the two component parts of the shuttle transport will separate. The takeoff stage will make a 120° turn and drop back into the atmosphere, where it will perform any necessary maneuvers and land at an ordinary aircraft landing field, which will have to be at least 3 km long. At the same time, the two engines of the orbital stage will be turned on, and it will continue to rise into space for approximately another 9.6 km, after which it will be put into Earth orbit. Whenever the orbital stage has completed its task, it can turn off its engines to leave orbit and return into the atmosphere. Like the takeoff stage, the orbital stage can land at an ordinary airfield.

Having a total payload of 20 tons, the orbital stage will be able to carry both passengers (probably 12 persons) and freight. The freight compartment will be 18 meters long and 4.5 meters in diameter and, thus, will be large enough to carry a

satellite with a powerful launching stage. The orbital stage can, thus, be regarded as the possible first-stage of a two-stage booster for satellites and long-range space research stations and, also, as freight ships necessary for lunar colonies. On board the orbital stage there will be sufficient reserves of food, oxygen, and water to permit astronauts to remain in orbit for several weeks. /62

With regard to clothing, the passengers and crew members of the space shuttle will resemble modern airplane passengers much more than the astronauts shackled into their huge spacesuits. Both the takeoff and orbital stages will maintain an environment natural to humans. Nevertheless, in the interest of safety, the passengers and crew of the space shuttle and the other craft in the space transportation system will be provided with special light suits for use in extraordinary circumstances. This suit is already being developed at the present time. It weighs only 4 kg and can be folded and carried in a briefcase. It is recommended that the suit be worn during the periods of the space flight that are potentially dangerous to the passengers — for example, during the takeoff, atmosphere re-entry, and transfers from one ship to another. The flexibility of the suit allows it to be put on within a few minutes.

The principal economy of the space shuttle lies in the possibility of multiple use. The ship is expected to make 100 flights, and this number may possibly be increased. In addition, it will take no more than two weeks to get it ready for a new flight. On a round-the-clock schedule, this preparation time could be reduced to 3 1/2 days. Maxwell Hunter, the designer of the space shuttle for the Lockheed Aircraft Corporation, feels that the 3 1/2 day cycle of shuttle preparation will permit more flights to be made and will, accordingly, reduce the cost

of each kilogram of payload carried by the shuttle transport to a few tens of dollars.

A second spacecraft recommended by the Special Commission on Space Research is the spacetug. Like the shuttle, the spacetug will be a multipurpose craft with a long working life. The spacetug will consist of two parts: a takeoff module, which, /63 according to current proposals, will be about 7.5 meters long and 6.6 meters in diameter, and a living module designed to hold three to six persons. In some cases, the living module would be fitted with manipulators (mechanical arms) with long-range controls, similar to those now used to work with radioactive materials under laboratory conditions. With this equipment, the spacetug could be used to construct space stations, repair satellites, and load or unload the orbital stage of the shuttle transport.

The spacetug could also be fitted with supports similar to those on the Apollo lunar module and, thus, could provide transportation for passengers and freight between stations in lunar orbit and the surface of the Moon. The spacetug could then carry 10,000 kg of payload down to the Moon and, without refueling, return to lunar orbit with a payload of 3,000 kg.

The third type of spacecraft included in the combined system of space transportation will be the "orbit-to-orbit" ships. As is clear from the name alone, a transport craft of this type will always be in space, forming the link between the orbits around the two planets. Theoretically, to be most efficient and economical, such a transport should be powered by nuclear energy. For the first models, however, chemical fuel will be used, in order to maintain the principle of universality.

Nonetheless, even given the existence of the complex space transportation system described above, it will at first be a relatively expensive undertaking to place men and freight on the Moon, since it will cost 15 times as much to put them on the Moon as it will to put them on a spacecraft in Earth orbit. The /64 cost of transporting one kilogram by means of the "orbit-to-orbit" transport and the spacetug will be approximately 3,800 dollars. According to NASA estimates, the increasing use of the complex space transportation system in the next three decades will reduce the cost of transporting one kilogram to 100 dollars by the year 2,000. The cost could be greatly reduced by producing liquid hydrogen and liquid oxygen on the Moon and using them for the lunar portions of the systems.

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